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A SIMULATION FACILITY FOR TESTING SPACE STATION ASSEMBLY PROCEDURES

Ankur R. Hajare, Daniel T. Wick, and Nagy M. Shehad
Enhanced Technologies
Houston, Texas

ABSTRACT

NASA plans to construct the Space Station *Freedom* (SSF) in one of the most hazardous environments known to humankind - space. It is of the utmost importance that the procedures to assemble and operate the SSF in orbit are both safe and effective. This paper describes a facility designed to test the integration of the telerobotic systems and to test assembly procedures using a real-world robotic arm grappling space hardware in a simulated micro-gravity environment.

INTRODUCTION

NASA plans to construct the Space Station *Freedom* (SSF) in one of the most hazardous environments known to humankind - space. It is of utmost importance that telerobotic systems and procedures to assemble and maintain the SSF are both safe and effective. In addition, it is equally important that the mechanical attachment devices of the SSF function as planned. To ensure that the systems and procedures will meet all safety requirements, NASA is developing the Space Systems Automated Integration and Assembly Facility (SSAIAF). This facility will test the *integration* of flight systems, the telerobotic systems, and humans that will be involved in the assembly and maintenance of the SSF. Both mechanical and dynamic performance of these elements in a micro-gravity environment will be tested using real-time simulations.

Traditionally, the approach to building such hardware-in-the-loop, human-in-the-loop simulations has involved development of unique software to support each scenario. This scenario-specific approach results in continuous software development and maintenance, which consumes large portions of a project's budget and can adversely affect a project's schedule. A proposed SSAIAF software architecture, Simulation and Control Environment (SCE), will support the development of generic software components, called modules, that can be reused in numerous simulation scenarios. This approach will reduce the requirements for new simulation development.

This paper presents a brief overview of the SSAIAF. This is followed by a more in-depth description of the SCE proposed to be used by SSAIAF in developing the real-time simulations. The paper concludes with a description of how the SSAIAF can support the development of telerobotic procedures and space systems.

SSAIAF SYSTEMS

SSAIAF systems will provide the resources for all testing and development activities undertaken in the facility. The SSAIAF systems are shown graphically in Figure 1.

Computing Resources

Computing systems in this environment include hardware with sufficient processors, memory and I/O capacity to support two simultaneous tests on SSAIAF systems. The currently envisioned system will include three host computers, peripherals, and computer control consoles.

Manipulator Development Facility

The Manipulator Development Facility (MDF) is a stand-alone system that provides a realistic test and training environment for astronauts who will use the Shuttle arm. The MDF permits astronauts or test engineers to lift structural components out of a mockup of the Space Shuttle Orbiter cargo bay and position them for deployment or erection.

Mobile Remote Manipulator Development Facility

The Mobile Remote Manipulator Development Facility (MRMDF) is a stand-alone system that provides a realistic test and training environment for astronauts who will use the Space Station arm. The MRMDF permits astronauts or test engineers to grapple and position a station payload, a platform, and another object for deployment or erection on the Space Station.

Air -Bearing Floor

The Air-Bearing Floor (ABF) is a large, smooth surface area (21.3 meters by 27.4 meters) upon which pallets can float on a cushion of air. Each pallet can carry over 453.6 Kg (1000 lb) of weight. The cushion of air permits the pallets to move in two dimensions as if there were no friction. Thus, the air-bearing floor simulates weightlessness in two dimensions.

Six-Degree-of-Freedom Dynamic Testing System

The Six-Degree-of-Freedom Dynamic Testing System (SDTS) is a computer-controlled hydraulic table (Stewart Platform) that can move in six planes of motion at one time (right/left, back/forward, up/down, pitch, yaw, and roll). The SDTS can lift large objects weighing up to 4536 Kg (10,000 lb) and move them to a position, as directed, within a tolerance of 0.25 cm (0.1 inch). The orientation of the SDTS is such that it usually moves objects vertically.

Simulation and Control Environment

The Simulation and Control Environment (SCE) is a software system that integrates all elements required for the development of SSAIAF real-time simulations in a comprehensive and cost effective application generation environment. The modular approach allows the reusability of software developed for previous simulations. The SSAIAF simulations developed using the SCE will execute on the test computing systems. SCE development activities utilizing a user-friendly, icon-driven user interface will be accomplished on development/maintenance workstations. The SCE architecture and usage is further discussed below.

THE SIMULATION AND CONTROL ENVIRONMENT

SCE Architecture

The proposed software architecture for SCE will include both Commercial-Off-the-Shelf (COTS) and custom components. SCE uses a layered architecture (Figure 2) that supports modular and reusable software modules as well as application generation techniques that provide fast development and ease of change. The SCE has been designed in a modular architecture for three reasons. First, this modular approach supports the maintenance of the entire system. This permits system maintainers and developers to revise and update any particular module without affecting the entire SCE. This modular design is also POSIX compliant so that it can be easily migrated to other platforms as hardware continues to evolve.

The second reason for this architecture is to support an automated approach to the development of simulations. The SCE is designed to maximize the reuse of previous development efforts. To this end, a developer can select a highly developed software module or portions of previous simulations and incorporate those in a new effort. For example, a developer could select arm models from one simulation and propulsion models from another and combine those in a new simulation. Thus, a developer has the ability to reuse software at any level that is most appropriate for the development effort being undertaken.

The third reason for this architecture is to facilitate simulation generation by automating many attributes traditionally determined by the simulation designer. For example, a simulation executive/scheduler within the SCE will automatically allocate software modules (processes) to one or more CPUs communicating through shared memory, in order to maximize the efficiency of the simulation. In the traditional approach these decisions would be made by a designer in an arbitrary way and evaluated in a trial-and-error manner.

Major SCE Elements

The SCE is comprised of four major elements (Figure 3). First, the math models are implemented in the form of modules and can be considered as building blocks for the simulation developer. The modules themselves are built using lower level primitives.

The second element is an icon-based user interface that allows the simulation developer to define a particular simulation using a flow diagram-like notation that expresses the data-dependencies between the various modules, the simulation rates, delays, etc. The data representing a particular simulation are then stored as a set of Simulation Definition File(s). The third element is an application generator that translates the data created by the simulation definition element into another set of files called the Simulation Data File(s) and Executive Input File(s). The Executive Input File(s), which are generated following test computer dependent directives, are then shipped to the test environment, in addition to the simulation initialization data. The fourth element of the SCE, which is resident on the test computer complex, uses the Executive Input File(s) to setup the execution environment at run time and actually schedules and controls the simulation and automatically allocates parallel processes (when available) to multiple CPUs.

Simulation Life Cycle Using SCE

The use of the SCE in the simulation life cycle is displayed in Figure 4. The life cycle begins with the generation of simulation requirements. If existing SCE capabilities cannot support these requirements, SCE or Module developers will develop additional capabilities, e.g. a robot model, to support the simulation requirements.

Once the necessary capabilities are available, a simulation is defined and developed. This might include combining a Space Station Freedom model, a robot model, and ephemeris modules (gravity, solar, etc.) into a simulation. The simulation is generated using pre-developed modules and tested. Once the simulation is verified, the end user will run the simulation and evaluate the results.

DEVELOPING ON-ORBIT PROCEDURES

Rapid Procedures Development

The SCE will support rapid prototyping of procedures by permitting the user to select modules ranging from simple to complex, and to combine the modules in a simulation to investigate the action of these systems in space. The system will contain modules for the Space Station systems and environment (gravity and solar), and it will automatically combine these complex modules into a testable simulation. These will be displayed in the trainer's workstation screen. The trainer will then run a simulation using various scenarios.

Procedures Test and Verification

The SSAIAF will be designed to move flight-like articles as they would move in space to provide form-and-fit verification testing over a range of possible conditions. The SCE will support the evaluation of the complex dynamics and forces that cannot be tested elsewhere. The procedures using actual space systems can be tested utilizing SSAIAF test systems. Repeated and long term testing is possible, as well as off-nominal operations (e.g., collisions).

Astronaut Training

Upon procedure verification, the SCE will support training of astronaut-robot teams to ensure that their tasks can be accomplished in a safe and efficient manner. Experience has shown that real-time simulation cannot provide all the hands-on training required to successfully complete mission training. Astronauts will be trained in the SSAIAF using either real space systems or volumetrically identical mock-ups. In addition, on the Space Station humans will have to work in conjunction with a robotic systems. Thus, actual or simulated testing of human-robot teams must be performed. The SSAIAF will provide as close to a realistic training environment for astronaut-robot teams as possible on earth.

Problem Resolution

Experience in space operations has shown that anomalous situations occur which require real-time resolution (e.g., utilizing a robot in an untested scenario). The SCE could support rapid prototyping of possible solutions and testing of untested robotic operations. Interfaces with Johnson Space Center operations could include data and voice links with Shuttle and Space Station astronauts as they try to resolve on-orbit problems.

A Repository of Simulation Objects

Finally, the SCE will serve as a repository of space systems models that can support the training required by future space systems. Future space systems will be designed and tested. The SCE will support the archiving of simulation modules and the results of prior testing for the benefit of future training program developers.

CONCLUSION

Space is one of the most hazardous environments in which humans must work. The difficulty of assembling, maintaining, and repairing systems has led NASA to develop a facility where the integration of procedures and systems can be tested simultaneously. Testing space systems prior to launch requires a simulated environment. As stated above, the traditional approach to building, such as human-in-the-loop simulations, has involved development of unique software to support each scenario. However, in the SSAIAF the SCE approach represents a departure from tradition. The modular design maximizes the reuse of previously developed simulations. An entire simulation need no longer be developed from "scratch." Instead, developers can combine components of previous efforts and concentrate their efforts on the unique elements of the new simulation. In addition, the modular design of the SCE supports its own maintenance and permits migration to new platforms as hardware continues to evolve. The result of this approach is an adaptable software environment that supports the rapid development and test of space systems and the procedures they require in a cost-effective manner.

ABBREVIATIONS

ABF	Air-Bearing Floor
COTS	Commercial Off-the-Shelf
CPU	Central Processing Unit
Kg	Kilogram
MDF	Manipulator Development Facility
MRMDF	Mobile Remote Manipulator Development Facility
NASA	National Aeronautics and Space Administration
SCE	Simulation and Control Environment
SDTS	Six-degree-of-freedom Dynamic Testing System
SSAIAF	Space Systems Automated Integration and Assembly Facility
SSF	Space Station *Freedom*

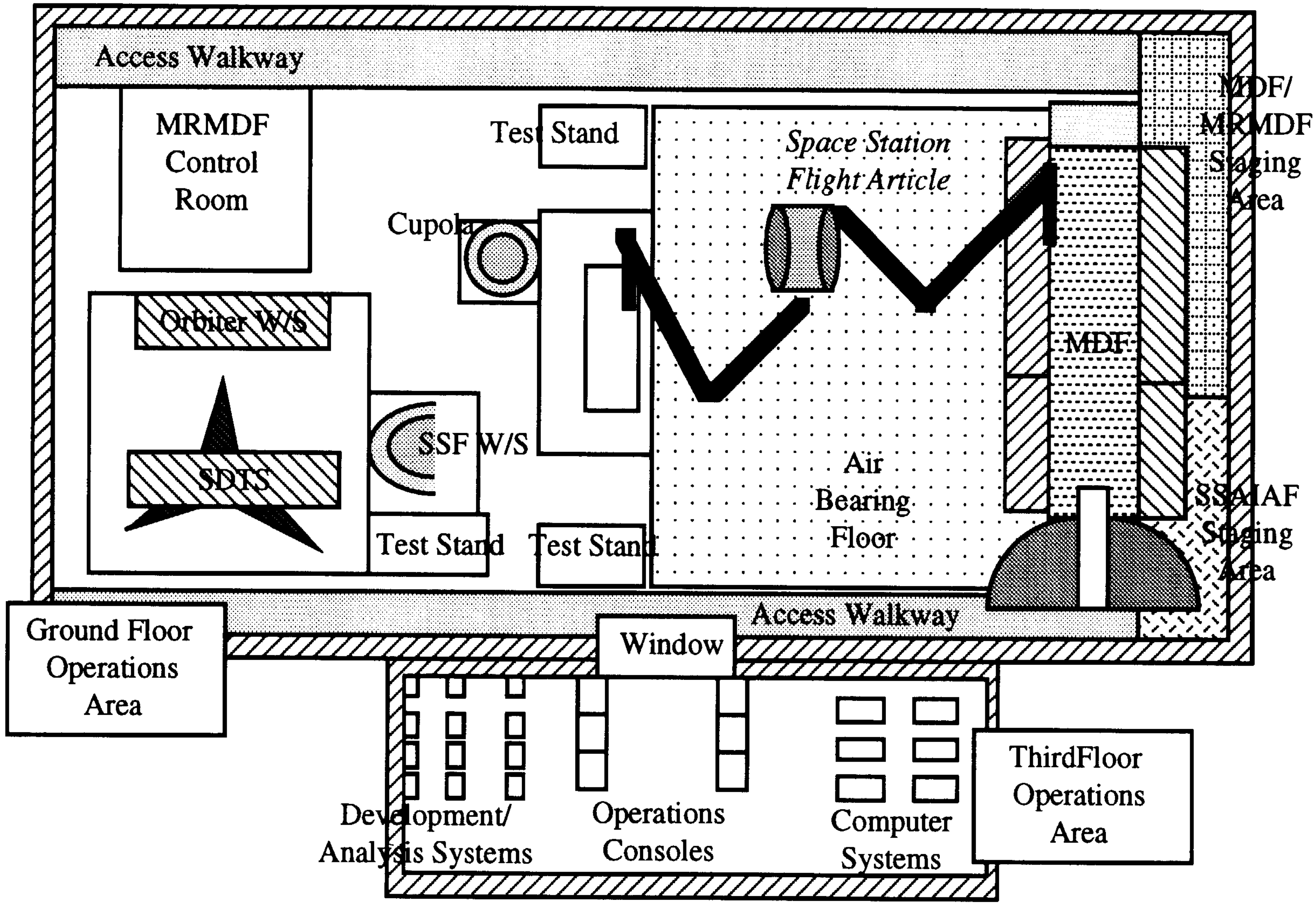

Figure 1. SSAIAF Systems

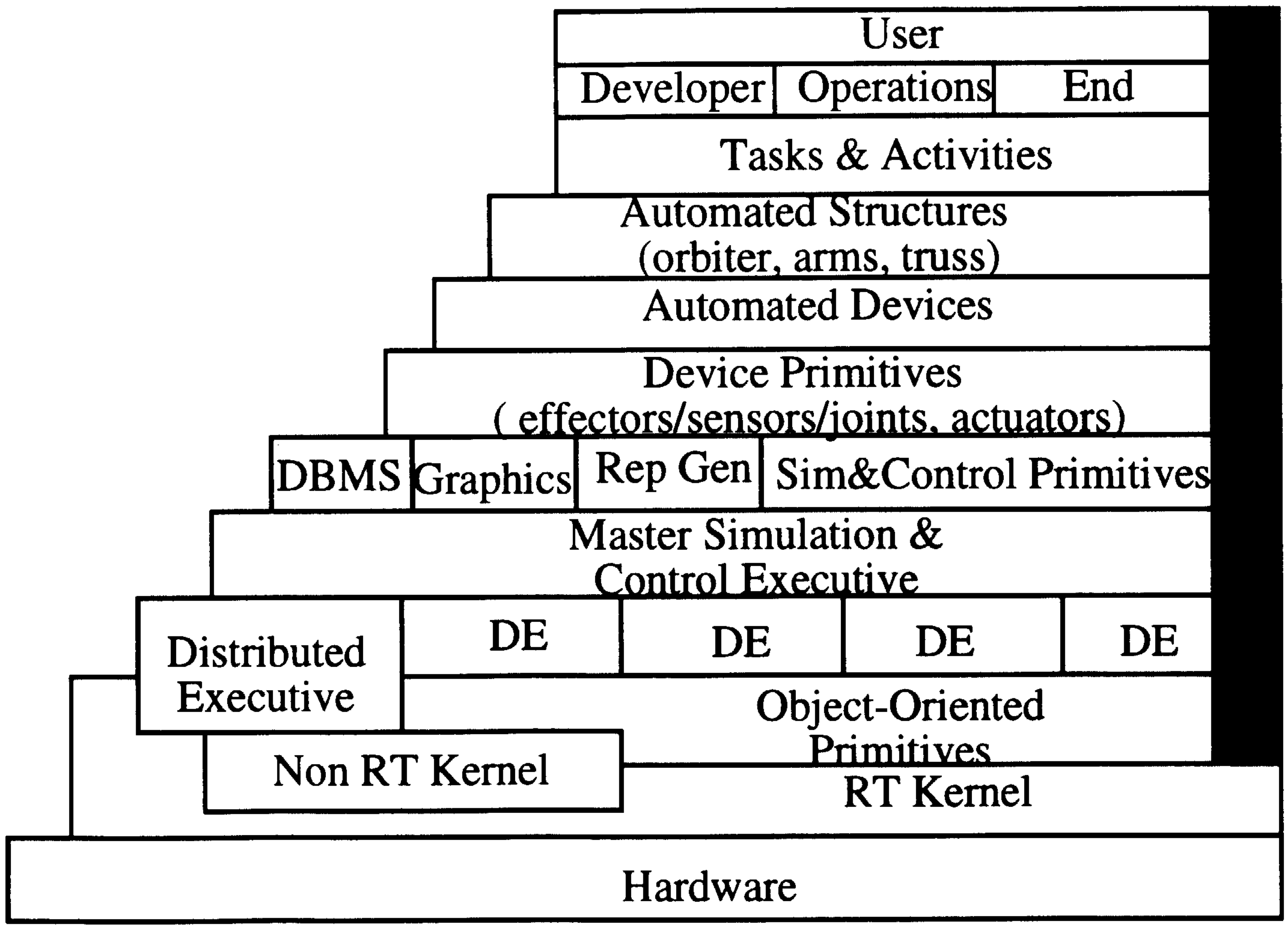

Figure 2. SCE Modular Design

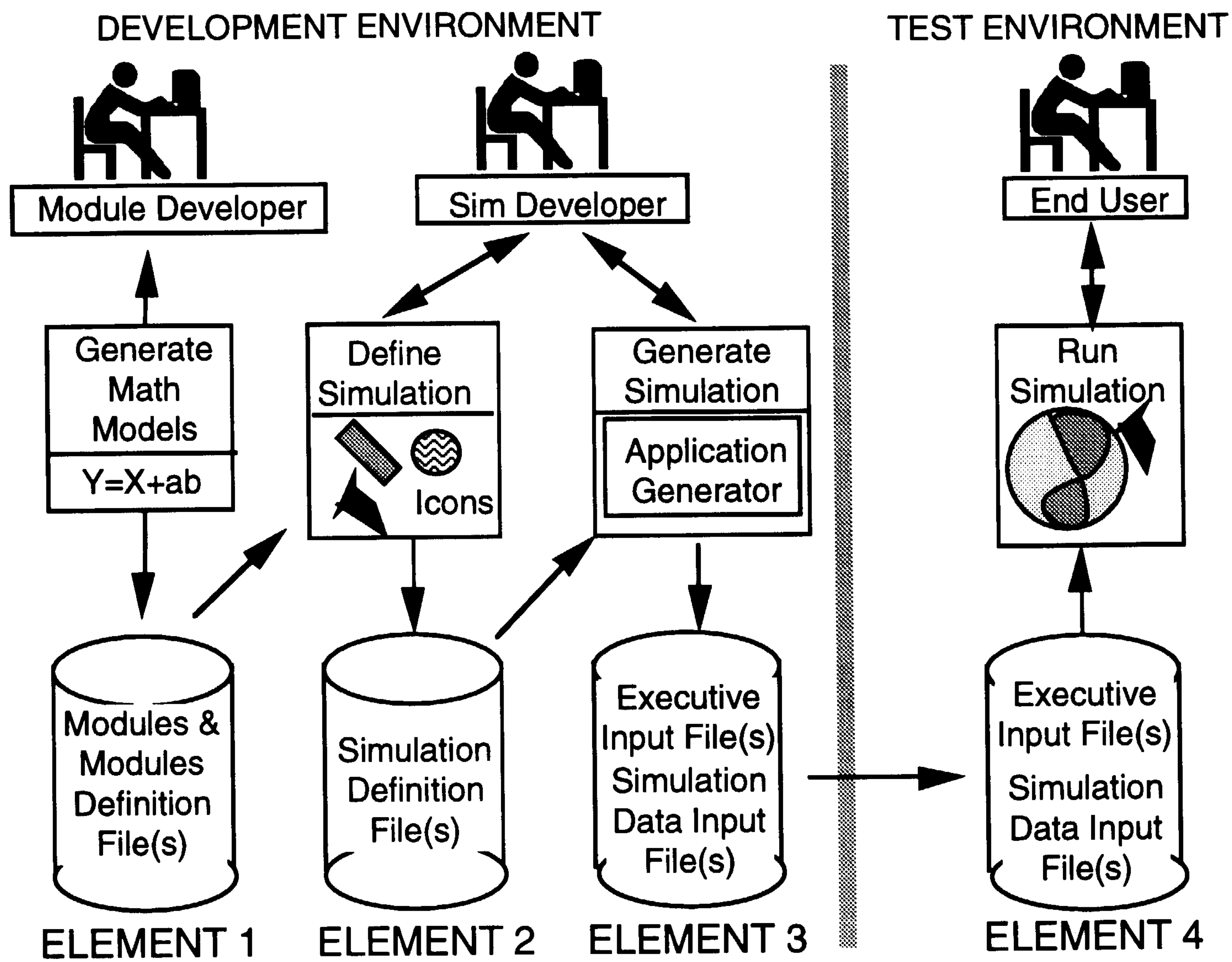

Figure 3. Major SCE Elements

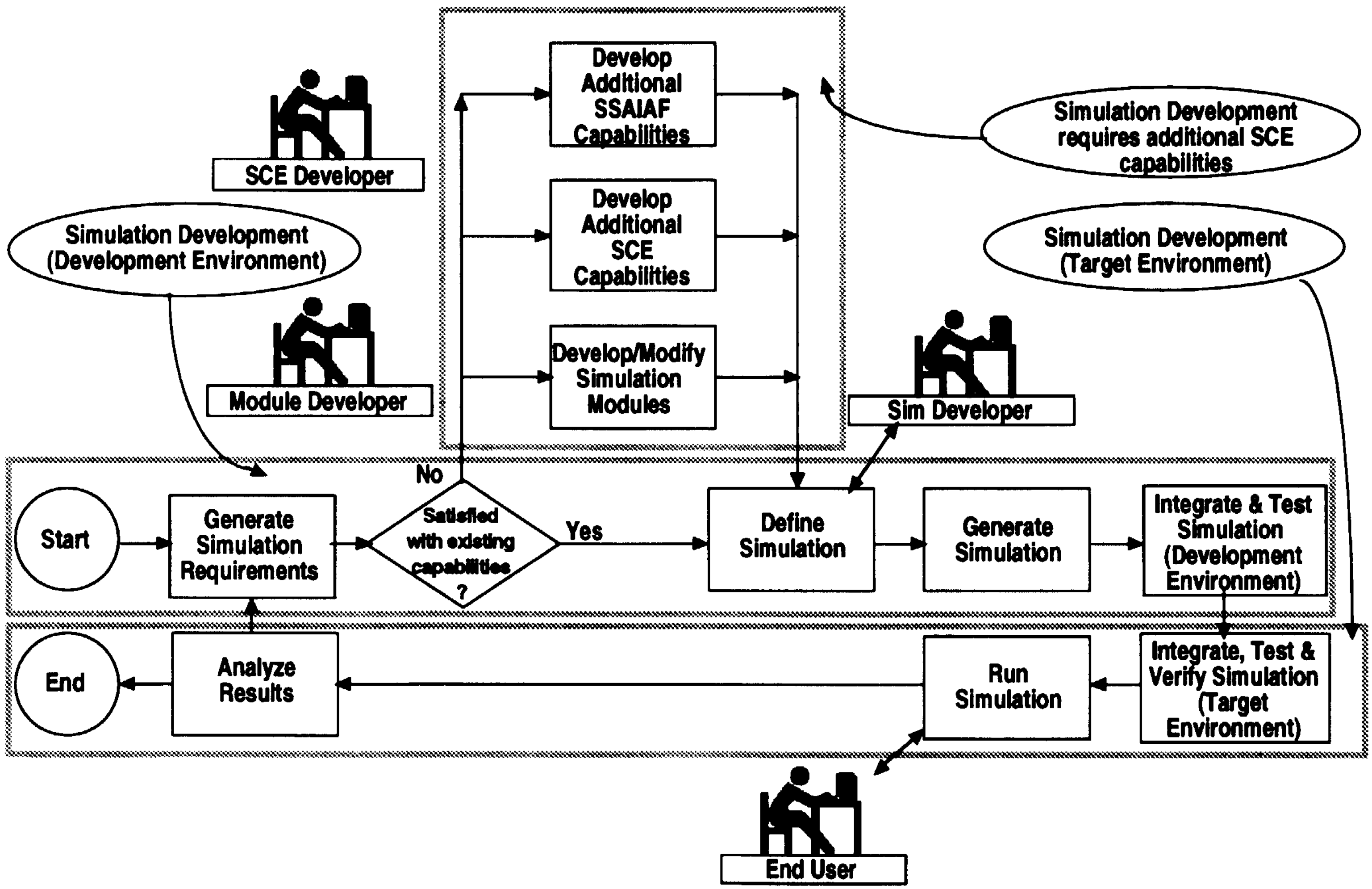

Figure 4. Simulation Life Cycle Using the SCE